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Economies of scale in bioenergy – theory vs practice

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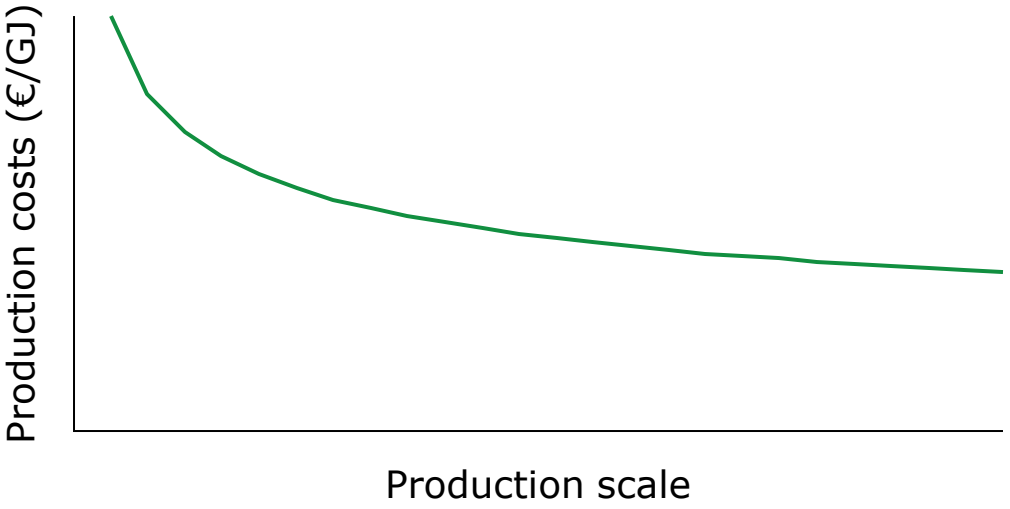
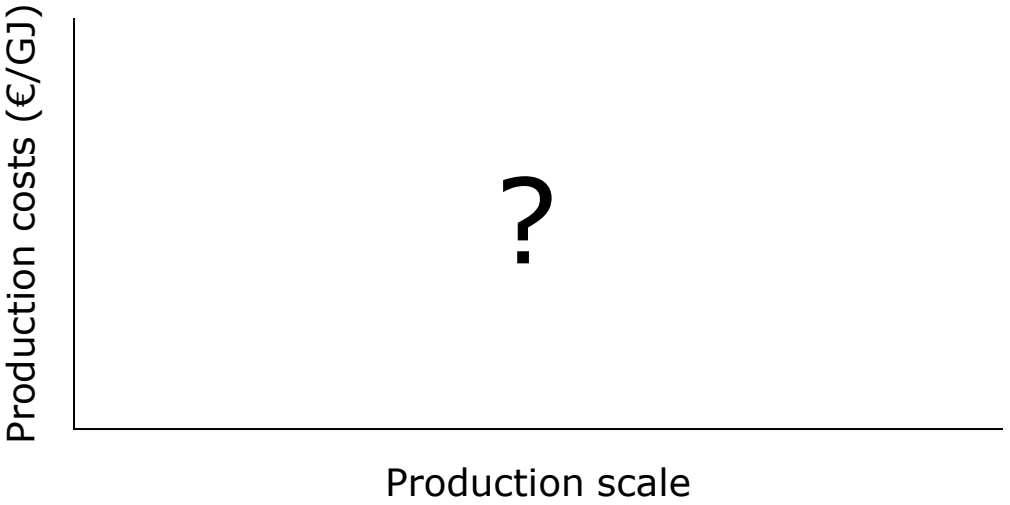
In the oil industry bigger is usually cheaper, in biofuel it is more complex

Oil industry

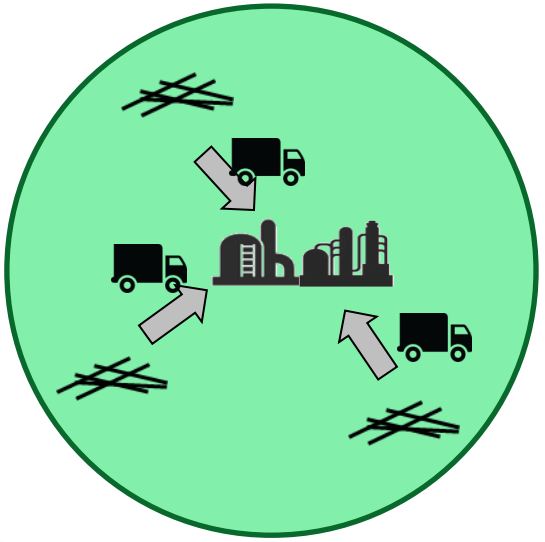


Biofuel

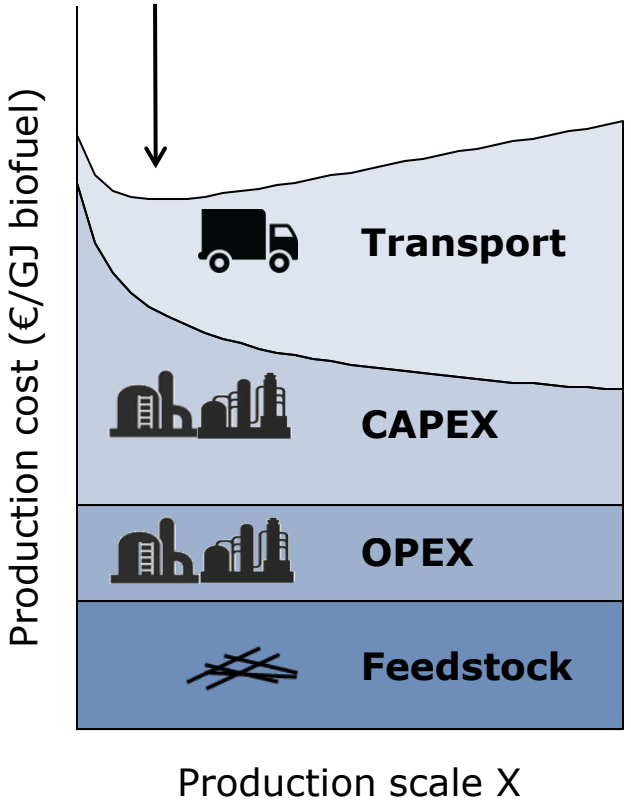


A stylized example of the biofuel supply chain

Our biofuel supply chain



Theoretical scale curve*



$\propto \beta X^{\frac{1}{2}}$, $where\ \beta \propto \frac{tc_v}{\rho^{\frac{1}{2}}}$

$\propto \alpha X^{sf-1}$, $where\ \alpha \propto I$

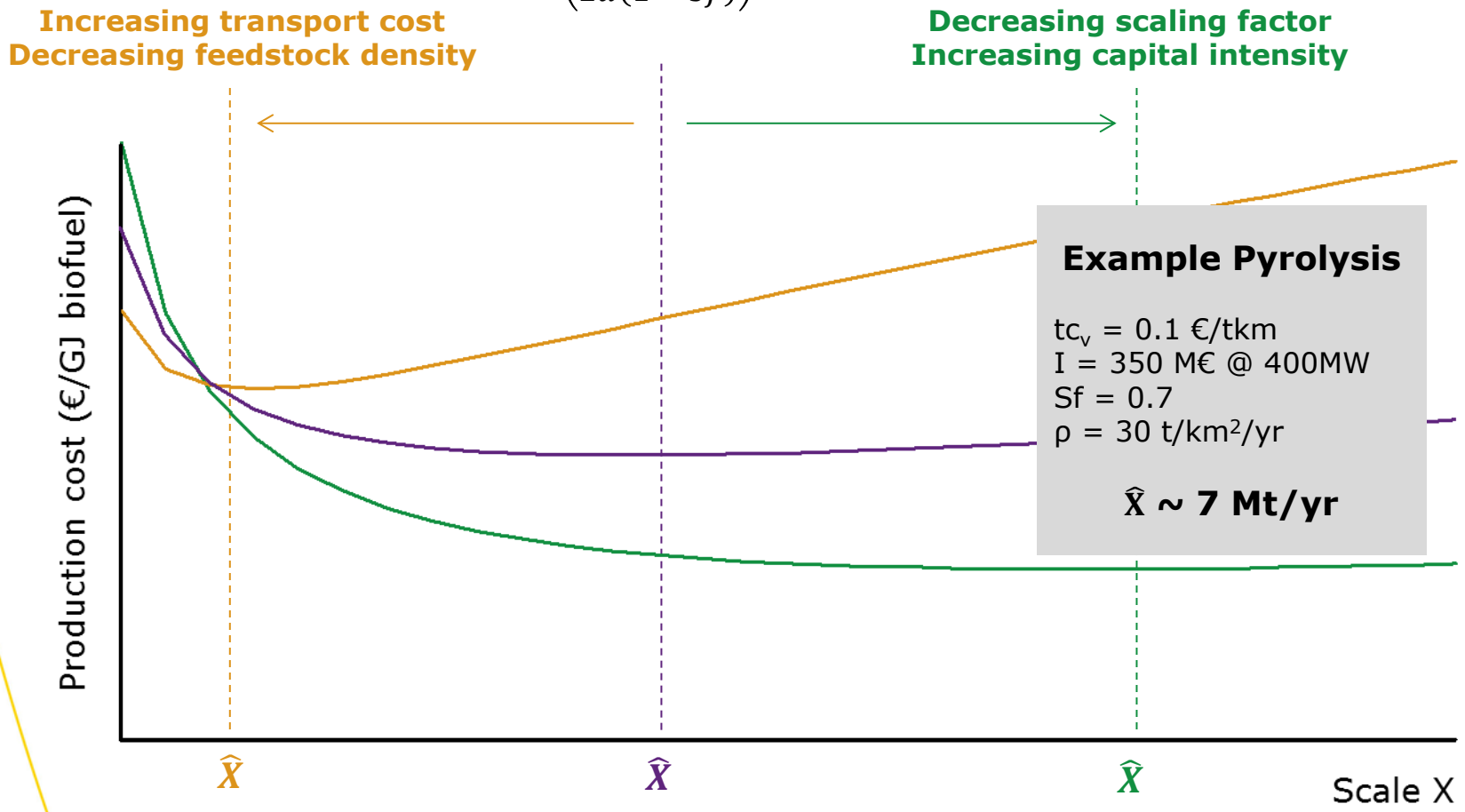
$constant\ with\ X$

$constant\ with\ X$

*Where X is scale, tc_v the variable transport cost, sf the scaling factor and I the investment

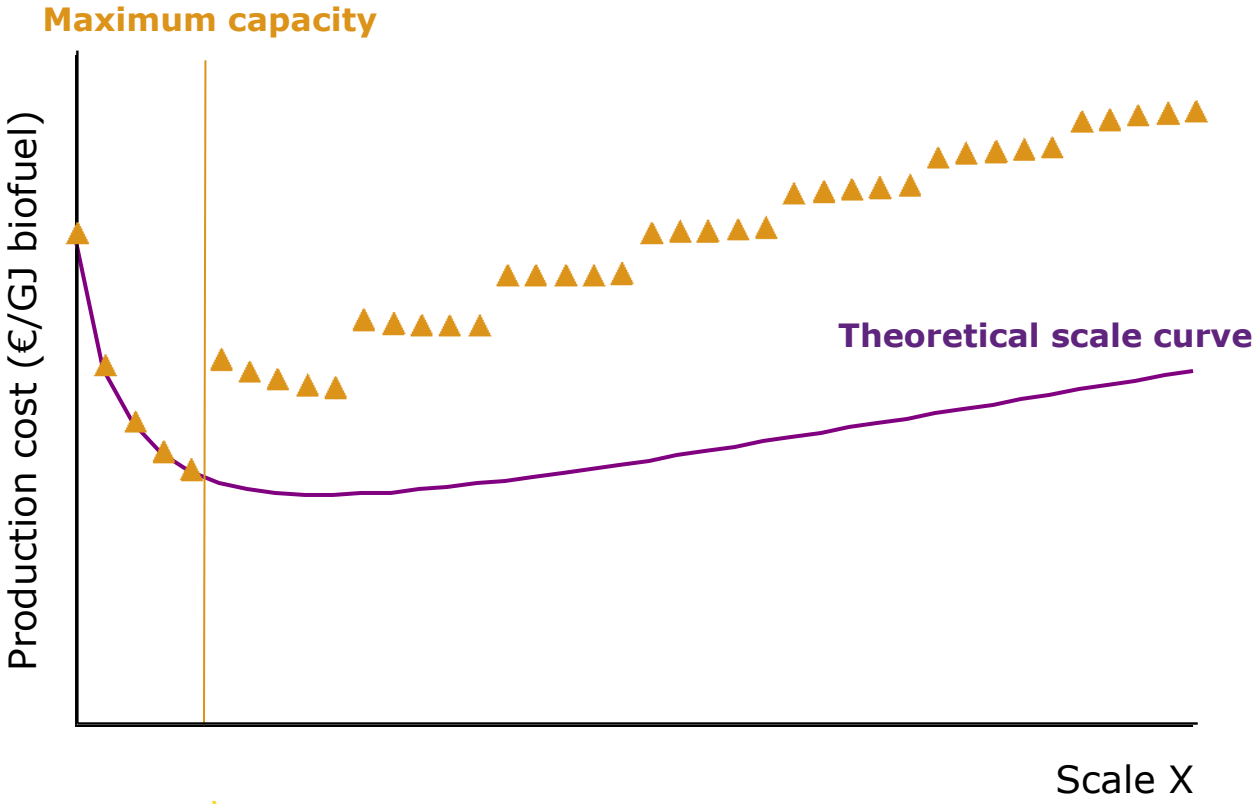
The optimal capacity $\hat{X}$ depends on technological scalability and capital intensity, feedstock density and transport cost

$$\hat{X} = \left(\frac{\beta}{2\alpha(1-sf)}\right)^{\frac{1}{sf-1.5}}$$



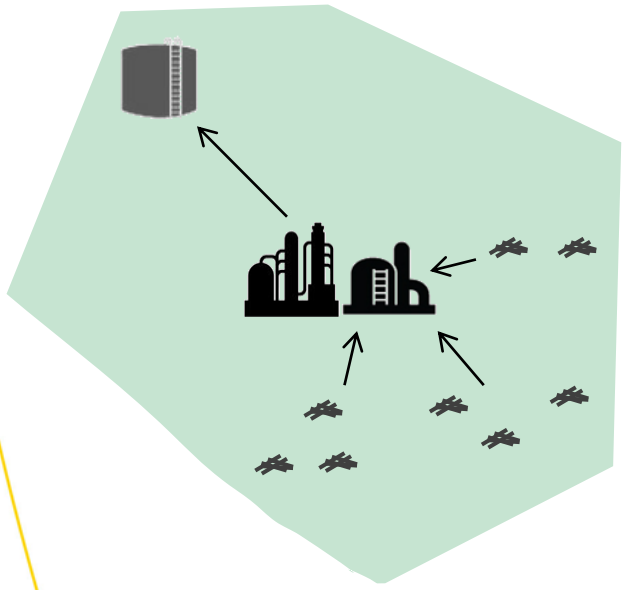
However, in practice there are more parameters which affect the theoretical scale curve

Maximum capacity
In practice, material limitations, shipping limits, site size and frame size may curb the size of (parts of) a conversion plant



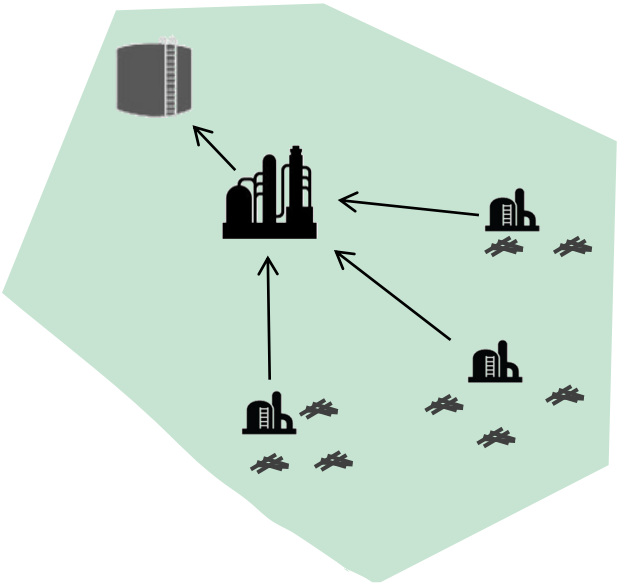
Distributed supply chain configurations can aid to limit the impact of growing transportation cost

Centralized supply chain



Lower CAPEX, higher transportation cost

Distributed supply chain



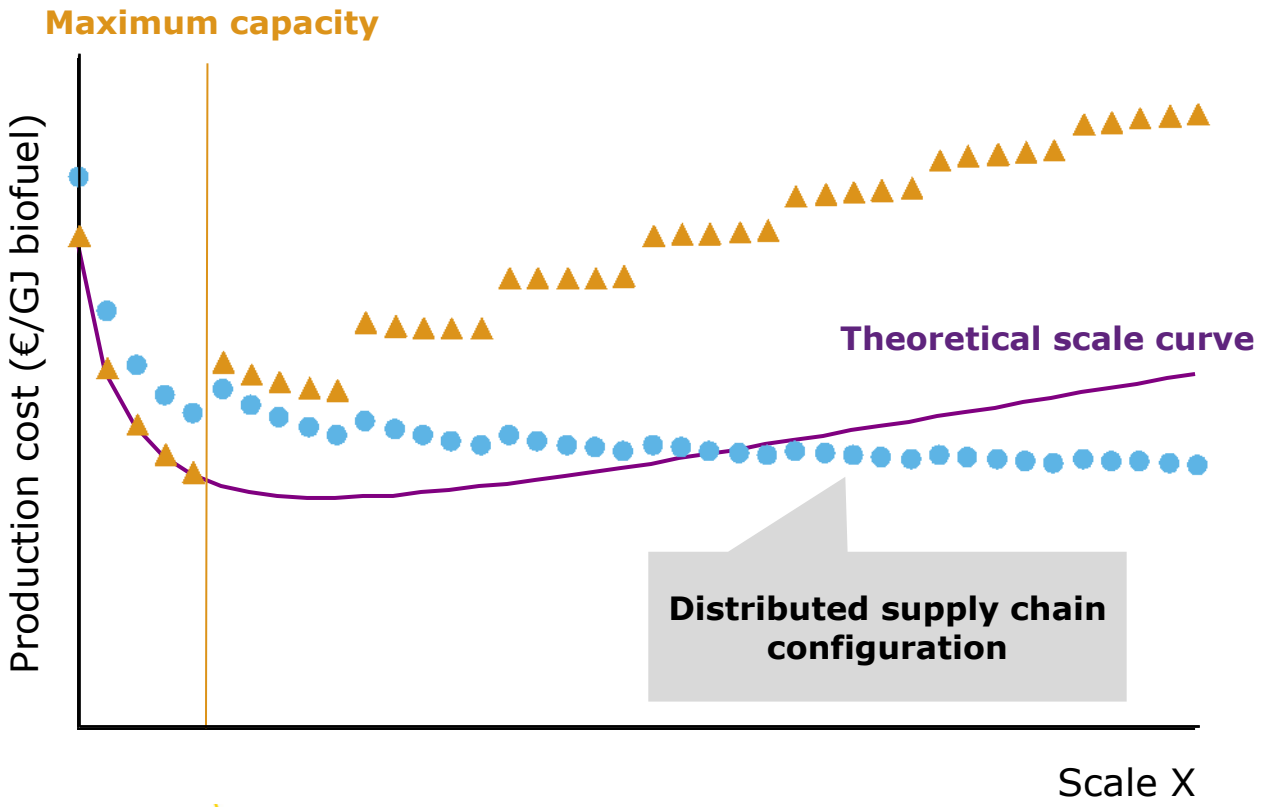
Higher CAPEX, lower transportation cost

Legend

- Feedstock
- Pre-conversion unit
- Conversion unit
- Storage terminal

However, in practice there are more parameters which affect the theoretical scale curve

Maximum capacity
In practice, material limitations, shipping limits, site size and frame size may curb the size of (parts of) a conversion plant



Additional factors affecting the scaling curve in practice, e.g.

- Maximum capacity
- Supply chain configurations
- Inhomogeneous feedstock density
- Inhomogeneous feedstock price
- Competing demand
- Transport infrastructure
- Transport modes
- Integration with host industries

We used an optimization model to develop a scale curve for biofuel production in Sweden

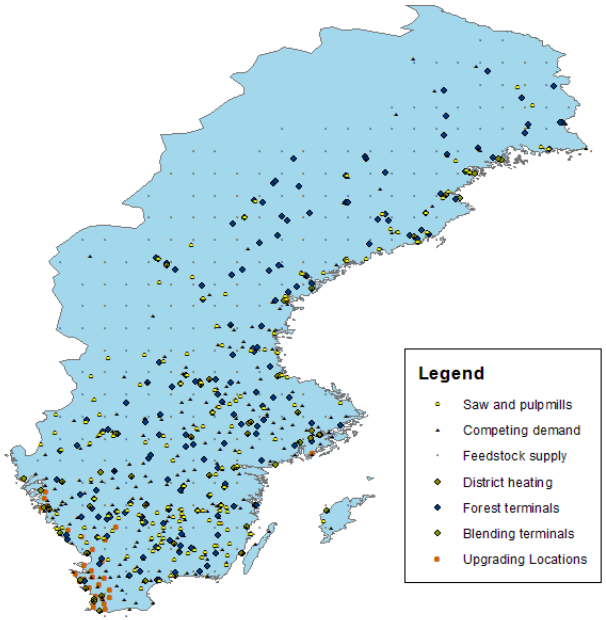
Techno-economic data

Feedstock → HTL* → Hydro-processing → Blending terminal

- CAPEX (dependent on scale & site)
- OPEX (dependent on site)
- Constraint on maximum capacity

*Hydrothermal liquefaction

Spatially explicit for Sweden



Feedstock supply & prices

- Forestry residues
- Byproducts from saw- and pulpmills
- Stumps
- Sawlogs
- Pulpwood

Competing feedstock demand

District heating | Pulp and paper | Sawmills

Conversion sites

- Forest terminals
- Pulpmills
- Sawmills
- District heating
- Refineries
- LNG terminals
- Natural gas pipeline connection

Transport modes

- Truck
- Train
- Short sea

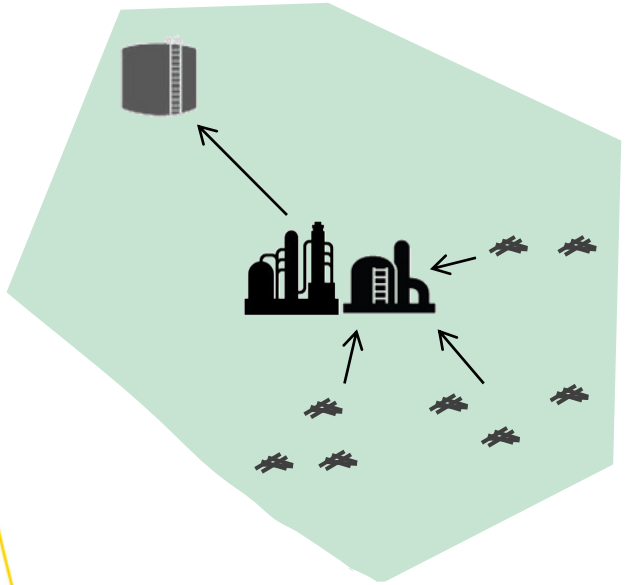
Linear optimization model

Optimizing system** cost for a given biofuel demand

**System = Biofuel & competing industry

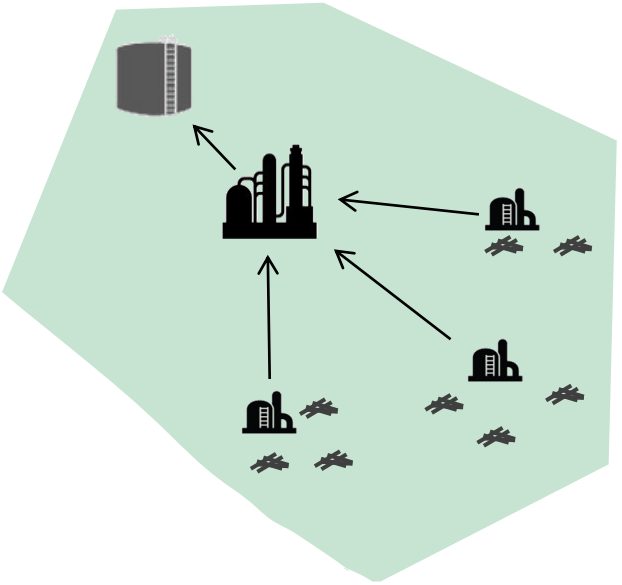
The model can choose between centralized and distributed supply chain configurations at different locations

Centralized supply chain



Potential locations: Refineries, natural gas grid connection, LNG terminal

Distributed supply chain



Potential HTL locations: Pulp mill, sawmill, district heating, forest terminals

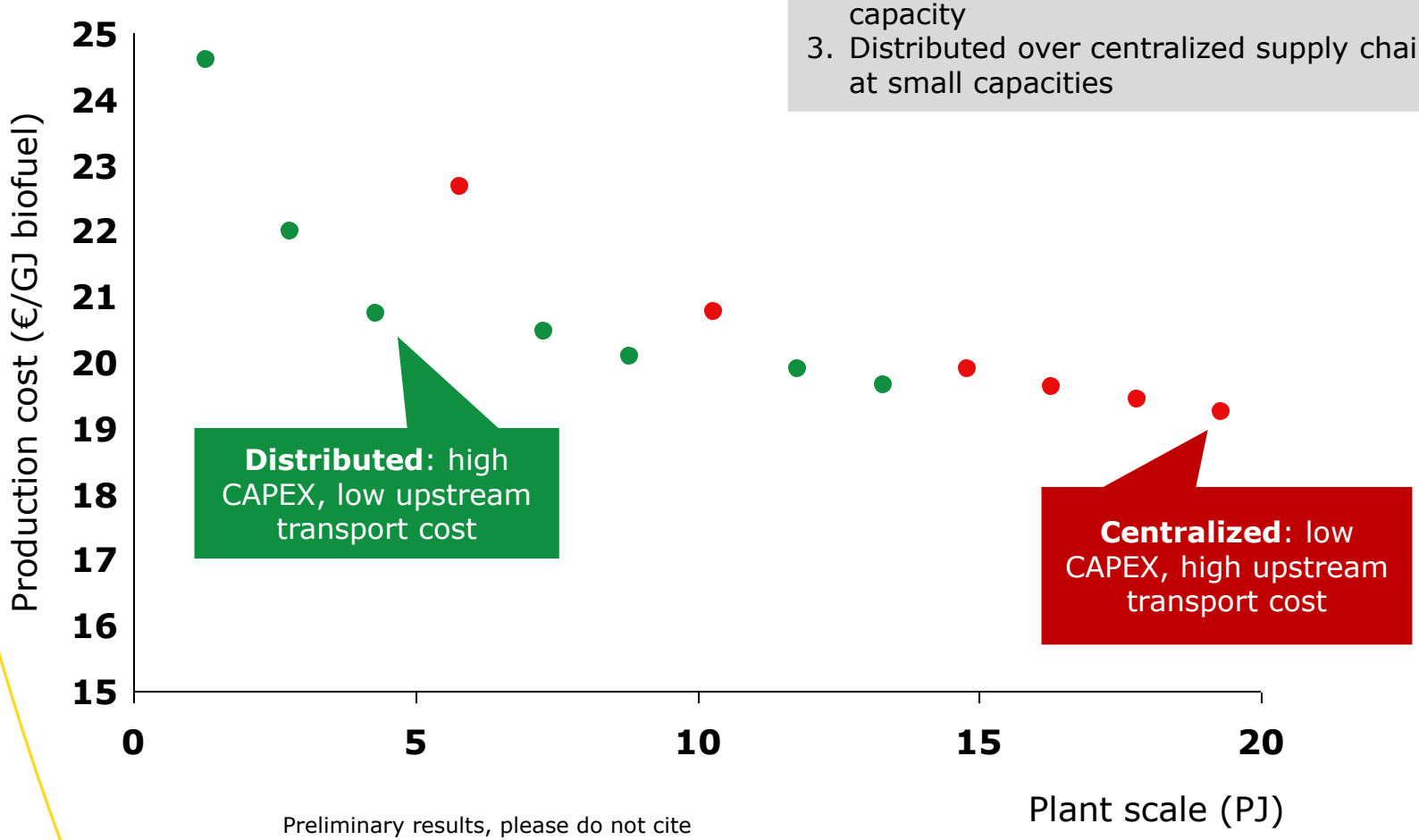
Potential upgrading locations: Refineries, natural gas grid connection, LNG terminal

Legend

- Feedstock
- HTL
- Hydroprocessing
- Storage terminal

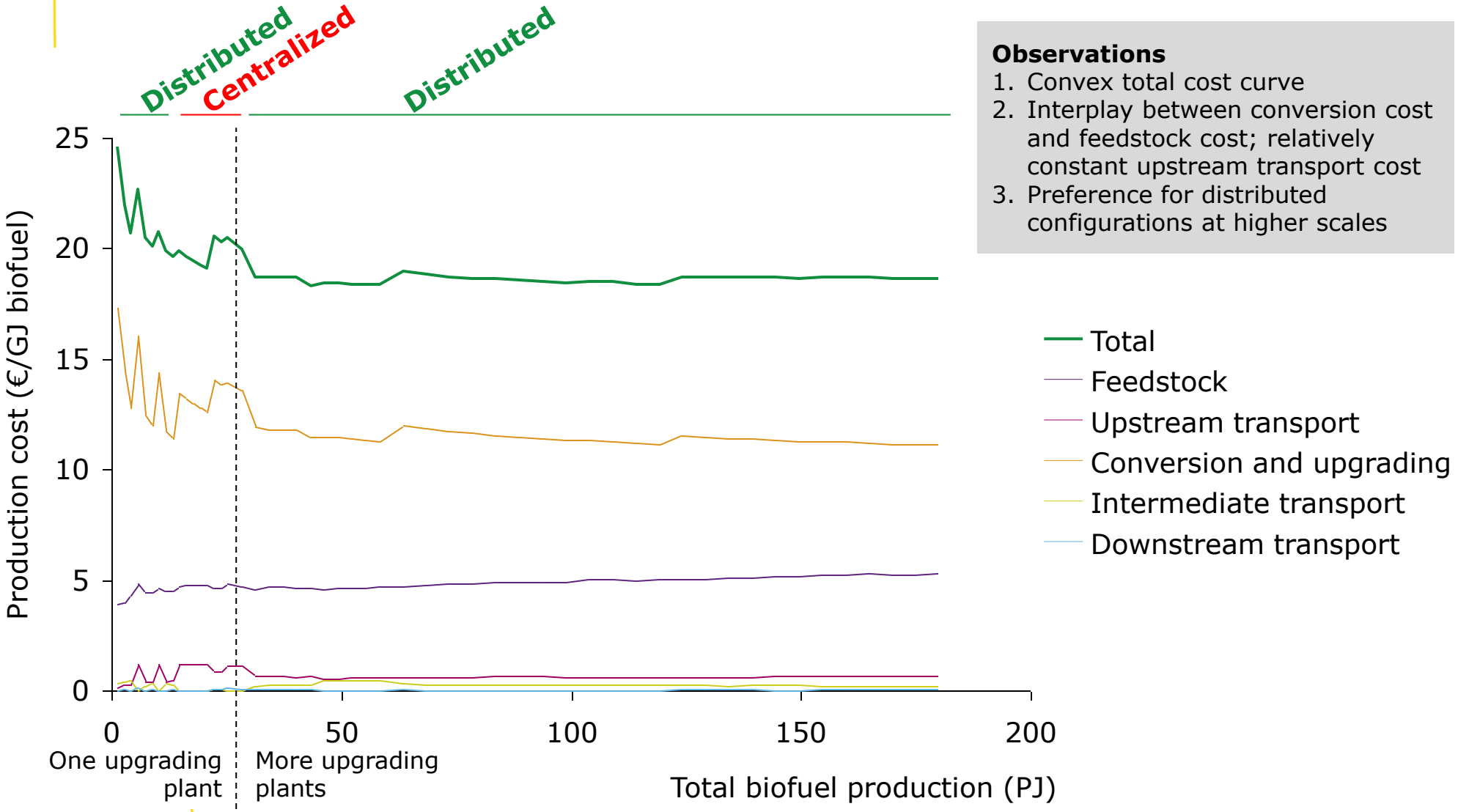
At a plant level economies of scale and the maximum capacity determine the shape of the scaling curve

Observations
1. Jigsaw curve due to maximum capacity
2. Downward trend beyond maximum plant capacity
3. Distributed over centralized supply chains at small capacities



Preliminary results, please do not cite

On a system level the cost curve has an upward tail which is caused by increasing feedstock prices, not by transport cost



Observations

1. Convex total cost curve
2. Interplay between conversion cost and feedstock cost; relatively constant upstream transport cost
3. Preference for distributed configurations at higher scales

Preliminary results, please do not cite

Preliminary conclusions

Key determinants for scaling	Economies of scale and maximum achievable capacity are the most important determinants in the biofuel scaling curve, not transportation costs *(unlike theory)*
Distributed vs. centralized	Distributed supply chain configurations are favored over centralized ones at small scale due to integration benefits and preferential siting *(unlike theory)*
System's perspective	From a system's perspective distributed supply chain configurations are favored, as there are limited locations at which centralized production makes sense (combination of high feedstock density and required utilities)

Thank you for your attention!

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